CLAIMS

1. A method of processing n-dimensional digital signals, n being an integer at least equal to 1, comprising the steps of:

   (a) providing an n-dimensional warped signal including n-dimensional warped coefficients and n-dimensional signal warping grids; and

   (b) computing warped wavelet packet coefficients and wavelet packet warping grids by applying an n-dimensional warped wavelet packet transform to said warped signal, with a binary tree where each node performs a one-dimensional warped subband processing along a respective dimension d, with $1 \leq d \leq n$.

2. A signal processing method according to claim 1, wherein $n = 1$.

3. A signal processing method according to claim 1, wherein $n > 1$ and said warped subband processing has a phase alignment coherent with said signal warping grids.

4. A signal processing method according to claim 3, wherein $n = 2$.

5. A signal processing method according to claim 3, wherein $n = 3$, and said n-dimensional digital signals are other than video image sequence signals.

6. A signal processing method according to claim 3, wherein $n > 3$.

7. A signal processing method according to any one of the preceding claims, wherein the step of providing the n-dimensional warped signal comprises:

   (a) receiving an n-dimensional digital input signal; and

   (b) computing said n-dimensional warped signal from said n-dimensional digital input signal.

8. A signal processing method according to any one of the preceding claims, wherein said signal warping grids are computed from a warping geometry defined by region parameters specifying a partition of a signal support into a plurality of regions and deformation parameters specifying geometrical deformation functions respectively associated with said regions, whereby the geometrical deformation function associated with one of the regions provides positions of sampling points within said one of the regions.

9. A signal processing method according to claim 8, wherein said regions comprise hyperrectangles and/or unions of hyperrectangles.

10. A signal processing method according to claim 8 or 9, wherein said geometrical deformation functions comprise directional deformation functions.

11. A signal processing method according to any one of claims 8 to 10, wherein $n = 3$ and the step of providing the n-dimensional warped signal comprises:

(a) receiving an n-dimensional digital input signal representing a video image sequence;

(b) estimating motion vectors within said video image sequence;

(c) determining at least one of said n-dimensional geometrical deformation functions by applying a time displacement to a 2-dimensional geometrical deformation using said estimated motion vectors; and

(d) computing said n-dimensional warped signal from said warping geometry and the received n-dimensional digital input signal.

12. A signal processing method according to any one of the preceding claims, further comprising the step of applying a bandeletisation to said warped wavelet packet coefficients and wavelet packet warping grids, wherein said bandeletisation comprises computing bandelet coefficients by applying invertible one-dimensional decorrelation operators to said warped wavelet packet coefficients along selected directions of said wavelet packet warping grids.

13. A signal processing method according to claim 12, wherein said wavelet packet warping grids have a decorrelation dimension equal to 1.

14. A signal processing method according to claim 12, wherein said wavelet packet warping grids have a decorrelation dimension larger or equal to 1 and said bandeletisation is implemented with phase-aligned warped wavelet packet transforms.

15. A signal processing method according to any one of claims 12 to 14, wherein at least one of said one-dimensional decorrelation operators performs a periodic decorrelation.

16. A signal processing method according to any one of claims 12 to 15, wherein said one-dimensional decorrelation operators are selected from the group consisting of warped wavelet subband processings, wavelet packet transforms, cosine transforms and sine transforms.

17. A signal compression method, comprising the steps of:

(a) receiving an n-dimensional digital input signal, n being an integer at least equal to 1;

(b) providing region and deformation parameters defining a warping geometry, wherein the region parameters specify a partition of an n-dimensional signal support into a plurality of regions and the deformation parameters are quantized and specify geometrical deformation functions respectively associated with said regions, whereby the geometrical deformation function associated with one of the regions provides positions of sampling points within said one of the regions;

(c) computing an n-dimensional warped signal including n-dimensional warped coefficients and n-dimensional signal warping grids from said warping geometry and the received n-dimensional digital input signal;

(d) computing warped wavelet packet coefficients and wavelet packet warping grids by applying an n-dimensional warped wavelet packet transform to said warped signal, with a binary tree where each node performs a one-dimensional warped subband processing along a respective dimension d, with $1 \leq d \leq n$;

(e) applying a bandeletisation to said warped wavelet packet coefficients and wavelet packet warping grids, wherein said bandeletisation comprises computing bandelet coefficients by applying invertible one-dimensional decorrelation operators to said warped wavelet packet coefficients along selected directions of said wavelet packet warping grids;

(f) quantizing said bandelet coefficients to produce quantized bandelet coefficients; and

(g) encoding said quantized bandelet coefficients and said region and deformation parameters into a multiplexed data stream suitable for storage in a storage medium or for transmission over a transmission medium.

18. A signal compression method according to claim 17 wherein $n > 1$ and said warped subband processing has a phase alignment coherent with said signal warping grids.

19. A signal compression method according to claim 17 or claim 18, wherein said wavelet packet warping grids have a decorrelation dimension larger or equal to 1 and said bandeletisation is implemented with phase-aligned warped wavelet packet transforms.

20. A signal compression method according to any one of claims 17 to 19, wherein at least one of said one-dimensional decorrelation operators performs a periodic decorrelation.

21. A signal compression method according to any one of claims 17 to 20, wherein said one-dimensional decorrelation operators are selected from the group consisting of warped wavelet subband processings, wavelet packet transforms, cosine transforms and sine transforms.

22. A signal compression method according to any one of claims 17 to 21, wherein said wavelet packet warping grids have a decorrelation dimension equal to 1.

23. A signal compression method according to claim 17 or claim 22, wherein $n = 1$ and at least of said one-dimensional decorrelation operators performs a periodic decorrelation.

24. A signal compression method according to any one of claims 17 to 22, wherein $n = 2$ and said regions comprise rectangles and/or unions of rectangles.

25. A signal compression method according to any one of claims 17 to 22, wherein $n = 3$, and said n-dimensional digital signals are other than video image sequence signals.

26. A signal compression method according to any one of claims 17 to 22, wherein $n = 3$ and the received n-dimensional digital input signal represents a video image sequence, and wherein the step of providing the parameters defining the warping geometry comprises:

(a) estimating motion vectors within said video image sequence; and

(b) determining at least one of said n-dimensional geometrical deformation functions by applying a time displacement to a 2-dimensional geometrical deformation using said estimated motion vectors.

27. A feature extraction method, comprising the steps of:

(a) producing a multiplexed data stream by carrying out a signal compression method according to any one of claims 17 to 26; and

(b) computing a feature vector from said multiplexed data stream.

28. A feature extraction method, comprising the steps of:

(a) receiving an n-dimensional digital input signal, n being an integer at least equal to 1;

(b) providing region and deformation parameters defining a warping geometry, wherein the region parameters specify a partition of an n-dimensional signal support into a plurality of regions and the deformation parameters specify geometrical deformation functions respectively associated with said regions, whereby the geometrical deformation function associated with one of the regions provides positions of sampling points within said one of the regions;

(c) computing an n-dimensional warped signal including n-dimensional warped coefficients and n-dimensional signal warping grids from said warping geometry and the received n-dimensional digital input signal;

(d) computing warped wavelet packet coefficients and wavelet packet warping grids by applying an n-dimensional warped wavelet packet transform to said warped signal, with a binary tree where each node performs a one-dimensional warped subband processing along a respective dimension d, with $1 \leq d \leq n$;

(e) applying a bandeletisation to said warped wavelet packet coefficients and wavelet packet warping grids, wherein said bandeletisation comprises computing bandelet coefficients by applying invertible one-dimensional decorrelation operators to said warped wavelet packet coefficients along selected directions of said wavelet packet warping grids; and

(f) computing a feature vector from said warping geometry and said bandelet coefficients.

29. A feature extraction method according to claim 28 wherein $n > 1$ and said warped subband processing has a phase alignment coherent with said signal warping grids.

30. A feature extraction method according to claim 28 or claim 29, wherein said wavelet packet warping grids have a decorrelation dimension larger or equal to 1 and said bandeletisation is implemented with phase-aligned warped wavelet packet transforms.

31. A feature extraction method according to any one of claims 28 to 30, wherein at least one of said one-dimensional decorrelation operators performs a periodic decorrelation.

32. A feature extraction method according to any one of claims 28 to 31, wherein said one-dimensional decorrelation operators are selected from the group consisting of warped wavelet subband processings, wavelet packet transforms, cosine transforms and sine transforms.

33. A feature extraction method according to any one of claims 28 to 32, wherein said wavelet packet warping grids have a decorrelation dimension equal to 1.

34. A feature extraction method according to claim 28 or claim 33, wherein $n = 1$ and at least one of said one-dimensional decorrelation operators performs a periodic decorrelation.

35. A feature extraction method according to any one of claims 28 to 33, wherein $n = 2$ and said regions comprise rectangles and/or unions of rectangles.

36. A feature extraction method according to any one of claims 28 to 33, wherein $n = 3$, and said n-dimensional digital signals are other than video image sequence signals.

37. A feature extraction method according to any one of claims 28 to 33, wherein $n = 3$ and the received n-dimensional digital input signal represents a video image sequence, and wherein the step of providing the parameters defining the warping geometry comprises:

(a) estimating motion vectors within said video image sequence; and

(b) determining at least one of said n-dimensional geometrical deformation functions by applying a time displacement to a 2-dimensional geometrical deformation using said estimated motion vectors.

38. A method of processing n-dimensional digital signals, n being an integer at least equal to 1, comprising the steps of:

(a) providing warped wavelet packet coefficients and wavelet packet warping grids; and

(b) computing a warped signal including n-dimensional warped coefficients and n-dimensional signal warping grids based on said warped wavelet packet coefficients and wavelet packet warping grids, with a binary tree where each node performs a one-dimensional inverse warped subband processing along a particular dimension d, with $1 \leq d \leq n$; and

(c) applying an inverse warping operation to said warped signal to produce an output signal.

39. A signal processing method according to claim 38, wherein $n = 1$.

40. A signal processing method according to claim 38, wherein $n > 1$ and said inverse warped subband processing has a phase alignment coherent with said signal warping grids.

41. A signal processing method according to claim 40, wherein $n = 2$.

42. A signal processing method according to claim 40, wherein $n = 3$ and said n-dimensional digital signals are other than video image sequence signals.

43. A signal processing method according to claim 40, wherein $n > 3$.

44. A signal processing method according to any one of claims 38 to 43, wherein the step of providing the warped wavelet packet coefficients and wavelet packet warping grids comprises:

(a) obtaining bandelet coefficients;

(b) obtaining parameters defining a warping geometry;

(c) computing said wavelet packet warping grids from said warping geometry; and

(d) computing said warped wavelet packet coefficients by applying an inverse bandeletisation to said bandelet coefficients, wherein said inverse bandeletisation comprises computing warped wavelet packet coefficients by applying inverse one-dimensional decorrelation operators to said bandelet coefficients, along selected directions of said wavelet packet warping grids.

45. A signal processing method according to claim 44, wherein the decorrelation dimension of said wavelet packet warping grids is at least equal to 1, and said inverse bandeletisation is implemented with phase-aligned inverse warped wavelet packet transforms.

46. A signal processing method according to claim 44 or claim 45, wherein at least one of said inverse one-dimensional decorrelation operators performs a periodic inverse decorrelation.

47. A signal processing method according to any one of claims 44 to 46, wherein said inverse one-dimensional decorrelation operators are selected from the group consisting of inverse warped wavelet subband processings, inverse wavelet packet transforms, inverse cosine transforms and inverse sine transforms.

48. A signal processing method according to any one of claims 44 to 47 wherein the decorrelation dimension of said wavelet packet warping grids is equal to 1.

49. A signal decompression method, comprising the steps of:

(a) receiving a multiplexed data stream representing a compressed n-dimensional digital signal from a transmission or storage medium, n being an integer at least equal to 1;

(b) decoding the received multiplexed data stream to obtain quantized bandelet coefficients and parameters defining a warping geometry;

(c) computing wavelet packet warping grids from said warping geometry;

(d) computing warped wavelet packet coefficients by applying an inverse bandeletisation to said quantized bandelet coefficients, wherein said inverse bandeletisation comprises computing warped wavelet packet coefficients by applying inverse one-dimensional decorrelation operators to said quantized bandelet coefficients along selected directions of said wavelet packet warping grids;

(e) computing a warped signal including n-dimensional warped coefficients and n-dimensional signal warping grids based on said warped wavelet packet coefficients and wavelet packet warping grids, with a binary tree where each node performs a one-dimensional inverse warped subband processing along a particular dimension d, with $1 \leq d \leq n$; and

(f) applying an inverse warping operation to said warped signal to produce a decompressed version of said n-dimensional digital signal.

50. A signal decompression method according to claim 49, wherein $n > 1$ and said inverse warped subband processing has a phase alignment coherent with said signal warping grids.

51. A signal decompression method according to claim 49 or claim 50, wherein said wavelet packet warping grids have a decorrelation dimension larger or equal to 1 and said inverse bandeletisation is implemented with phase-aligned inverse warped wavelet packet transforms.

52. A signal decompression method according to any one of claims 49 to 51, wherein at least one of said inverse one-dimensional decorrelation operators performs a periodic inverse decorrelation.

53. A signal decompression method according to any one of claims 49 to 52, wherein said inverse one-dimensional decorrelation operators are selected from the group consisting of inverse warped wavelet subband processings, inverse wavelet packet transforms, inverse cosine transforms and inverse sine transforms.

54. A signal decompression method according to any one of claims 49 to 53, wherein the decorrelation dimension of said wavelet packet warping grids is equal to 1.

55. A signal decompression method according to claim 49 or claim 54, wherein $n = 1$ and at least one of said inverse one-dimensional decorrelation operators performs a periodic inverse decorrelation.

56. A signal decompression method according to any one of claims 49 to 54, wherein $n = 2$ and the warping geometry comprises regions consisting of rectangles and/or unions of rectangles.

57. A signal decompression method according to any one of claims 49 to 54, wherein $n = 3$, and said n-dimensional digital signals are other than video image sequence signals.

58. A signal decompression method according to any one of claims 49 to 54, wherein $n = 3$ and said n-dimensional digital signal represents a video image sequence.

59. A signal restoration method, comprising the steps of:

(a) receiving an n-dimensional digital input signal, n being an integer at least equal to 1;

(b) providing region and deformation parameters defining a warping geometry, wherein the region parameters specify a partition of an n-dimensional signal support into a plurality of regions and the deformation parameters specify geometrical deformation functions respectively associated

with said regions, whereby the geometrical deformation function associated with one of the regions provides positions of sampling points within said one of the regions;

(c) computing an n-dimensional warped signal including n-dimensional warped coefficients and n-dimensional signal warping grids from said warping geometry and the received n-dimensional digital input signal;

(d) computing warped wavelet packet coefficients and wavelet packet warping grids by applying an n-dimensional warped wavelet packet transform to said warped signal, with a binary tree where each node performs a one-dimensional warped subband processing along a respective dimension d, with $1 \leq d \leq n$;

(e) applying a bandeletisation to said warped wavelet packet coefficients and wavelet packet warping grids, wherein said bandeletisation comprises computing bandelet coefficients by applying invertible one-dimensional decorrelation operators to said warped wavelet packet coefficients along selected directions of said wavelet packet warping grids;

(f) applying a restoration process to said bandelet coefficients and said warping geometry to provide processed bandelet coefficients and processed warping geometry;

(g) computing processed wavelet packet warping grids from said processed warping geometry;

(h) computing processed warped wavelet packet coefficients by applying an inverse bandeletisation to said processed bandelet coefficients, wherein said inverse bandeletisation comprises computing processed warped wavelet packet coefficients by applying inverse one-dimensional decorrelation operators to said processed bandelet coefficients, along selected directions of said processed wavelet packet warping grids;

(i) computing a processed warped signal including n-dimensional processed warped coefficients and n-dimensional processed signal warping grids based on said processed warped wavelet packet coefficients and processed wavelet packet warping grids, with a binary tree where each node performs a one-dimensional inverse warped subband processing along a particular dimension d, with $1 \leq d \leq n$; and

(j) applying an inverse warping operation to said warped signal to produce a restored n-dimensional digital output signal.

60. A signal restoration method of claim 59 wherein said restoration process comprises applying a thresholding operator to said bandelet coefficients.

61. A signal restoration method according to claim 59 or claim 60 wherein $n > 1$ and said warped subband processing has a phase alignment coherent with said signal warping grids.

62. A signal restoration method according to any one of claims 59 to 61, wherein said wavelet packet warping grids have a decorrelation dimension larger or equal to 1 and said bandeletisation is implemented with phase-aligned warped wavelet packet transforms.

63. A signal restoration method according to any one of claims 59 to 62, wherein at least one of said one-dimensional decorrelation operators performs a periodic decorrelation.

64. A signal restoration method according to any one of claims 59 to 63, wherein said one-dimensional decorrelation operators are selected from the group consisting of warped wavelet subband processings, wavelet packet transforms, cosine transforms and sine transforms.

65. A signal restoration method according to any one of claims 59 to 64, wherein said wavelet packet warping grids have a decorrelation dimension equal to 1.

66. A signal restoration method according to claim 59 or claim 65, wherein $n = 1$ and at least one of said one-dimensional decorrelation operators performs a periodic decorrelation.

67. A signal restoration method according to any one of claims 59 to 65, wherein $n = 2$ and said regions comprise rectangles and/or unions of rectangles.

68. A signal compression method according to any one of claims 59 to 65, wherein $n = 3$, and said n-dimensional digital signals are other than video image sequence signals.

69. A signal restoration method according to any one of claims 59 to 65, wherein $n = 3$ and the received n-dimensional digital input signal represents a video image sequence, and wherein the step of providing the parameters defining the warping geometry comprises:

(a) estimating motion vectors within said video image sequence; and

(b) determining at least one of said n-dimensional geometrical deformation functions by applying a time displacement to a 2-dimensional geometrical deformation using said estimated motion vectors.

70. A signal processing apparatus, comprising computer means arranged to carry out a method according to any one of the preceding claims.

71. A computer program product, comprising instructions to carry out a method according to any one of claims 1 to 69 when said program is run in a computer processing unit.

72. A digital signal encoder to compress n-dimensional digital signals, comprising computer means arranged to carry out a signal compression method according to any one of claims 17 to 26.

73. A digital signal decoder to decompress n-dimensional digital signals, comprising computer means arranged to carry out a signal decompression method according to any one of claims 49 to 58.

74. A feature extraction engine to derive feature vectors from n-dimensional digital signals, comprising computer means arranged to carry out a feature extraction method according to any one of claims 27 to 37.

75. A pattern recognition system, comprising a feature extraction engine according to claim 74 to derive a feature vector from an n-dimensional digital input signal, and a comparison unit to compare said feature vector with stored feature vectors representing reference signals.

76. A digital signal restoration system, comprising computer means arranged to carry out a signal restoration method according to any one of claims 59 to 69.